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LATENCY AND AMPLITUDE CHARACTERISTICS OF

A CONDITIONED AUTONOMIC RESPONSE

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THE PROBLEM

Our general concern is with theories of interrelationships
among measures of conditioning. The experimental tests of such
theories require that more than one measure of the learning process
be obtained. Furthermore, the tests usually require that trial-by-
trial measures be secured on the same subjects undergoing condition-
ing of a single response. Of the three large classes of measures,
probability, amplitude, and time indices, probability (relative
frequency) is ruled out by the fact that it is empirically feasible
to obtain only one measurement per trial per subject. This leaves
time and amplitude measures. According to Hull (1), who has put
forth one theory of interrelationships of measures of conditioning,
time (latency) and amplitude measures can both be derived only from
the conditioning of autonomically mediated responses. The literature
does not provide us with numerous examples of such data, and none
in any form suitable for testing theories of interrelationships.

We were attracted by the recent work of Notterman, Schoenfeld,
and Bersh (2) who have successfully conditioned the human heart-
rate response. On the assumption that this response was representa-
tive of autonomic responses in general we have undertaken a replica-
tion of their experiment with a more detailed beat-by-beat analysis
of the response, and a more rigourous control for pseudo-conditioning.
This was done to allow the derivation of the latency characteristics
of the response and to assure the genuineness of the conditioning.
This was our specific purpose.

Although our general purpose was to collect data relevant to
the testing of theories of interrelationships, application of the
lengthy quantification procedures necessary for the actual testing
of theories is not done in this report. We are reporting here
simply the latency and amplitude characteristics of a presumably
representative autonomic response as a necessary but preliminary
step towards theory testing.

SUBJECTS, APPARATUS AND PROCEDURE

Subjects--. The subjects were 28 students at the University of
Connecticut ranging in age from 20 to 27 years. These were divided
into two groups, a Conditioning Group made up of 14 men and 3
women, and a Pseudo-conditioning Group consisting of 9 men and 2
women. All subjects were paid volunteers.

Apparatus--. In general the apparatus consisted of an electro-
cardiograph to measure the heart-rate, a source of shock for the US,
a tone for the C.S. and electronic timers for controlling the
sequence of stimuli.

More specifically the apparatus included a Garceau Electro-
encephalograph converted for use as an electrocardiograph and stimulus
recording kymograph, a Maico Audiometer for tone source, and a
Harvard inductorium as shock source. The durations of and interval
between CS and US were controlled by three Hunter Decade Interval
timers. The shock was 15 V.A.C. applied across the first two fingers
of the subject's left hand by means of copper electrodes covered
with electrode jelly. The tone, delivered through earphones, was set
at 60 db and 512 c.p.s. The subject was seated in a separate
cubicle, lined with acoustical celotex, having the dimensions $4\frac{1}{4}$' x
$4\frac{1}{4}$' x 8'. All the apparatus with the exception of the shock elec-
trodes, cardiograph leads and earphones were outside the subject's
cubicle. An electric fan in the wall of the cubicle provided ven-
tilation and an effective soundscreen for any cues from the experi-
menter or apparatus.

Procedure--. Parts of our procedure and technique were
closely patterned after those of Notterman, Schoenfeld and Bersh
(2). Each subject goes through two phases within the same $1\frac{1}{2}$ hr.
experimental session. For the first phase all subjects are given
a series of pre-conditioning trials consisting of the presentation
of 20 1-sec. tones spaced at irregular intervals of 1 to 2 minutes.
The second phase immediately follows this with 20 further trials of
either conditioning or pseudo-conditioning. A conditioning trial
consisted of a 1-sec. tone followed 6 sec. later by a six second
shock. During pseudo-conditioning the subject received on each
trial either a 1-sec. tone or a 6-sec. shock but not both. The
pseudo-conditioning trial sequence of tone (t) and shock (s) was
irregular: stttsttttttstttttsttstttttt. Intertrial intervals for
both conditioning and pseudo-conditioning varied irregularly between
1 and 2 min., as during pre-conditioning.

Cardiographic records were taken on each trial from about 20
sec. before the tone to 40 sec. after. Resulting cardiograms
looked similar to a published sample (2).

The subjects were instructed that they would receive a series
of tones and a series of shocks but the order was not mentioned.
The specific instructions were the same as those used by Notterman,
Schoenfeld, and Bersh (2).

RESULTS AND DISCUSSION

Plotting the form of the response.-- In the top half of Fig. 1 there are plotted the changes in heart-rate produced by the tone alone during the first 20 trials of pre-conditioning (solid line) and the changes produced by the tone and shock during the second 20 trials of conditioning. These functions are derived in the following way. On a single trial for one subject 35 heart-beat intervals are measured in millimeters from the cardiograph tape. There are ten beat intervals measured just before the onset of the tone, one beat measured during the tone, all the beats measured between the tone and the shock, all the beats measured during the shock period regardless of whether there is a shock or not, and finally ten beats after the shock period. These measurements are averaged over all 17 conditioning subjects for a single trial and then converted to beats/minute. An average is then taken over the first 20 trials to yield the pre-conditioning curve, and another average over the second 20 trials to give the form of the response during the conditioning trials.

The tone UR.--It can be seen that during the pre-conditioning period the average heart-rate was about 77 b/m for the ten beats prior to the tone onset. During the tone the rate drops about $1\frac{1}{2}$ b/m. Following the tone offset the rate undergoes a compensatory rise almost to the pre-tone level before showing a secondary depression and rise over the fourteen beats after the tone. There is also a suggestion of a tertiary depression and rise in the period marked 'post-shock' (no shock in pre-conditioning phase) completing the picture of the unconditioned response to tone of the human heart. The response can be described in general as a depression in rate followed by progressively damped oscillation.

The CR to tone.-- Attention to the dotted line in the top half of Fig. I reveals the change in heart response to tone brought about by its association with shock. The main effect of conditioning is the accentuation of the secondary depression. The magnitude of this depression from pre-tone level is about 4 b/m at its maximum point just before shock. This is a highly significant effect if we use the small pre-tone variability as a measure of experimental error. The curious fact may be noted that the last two beats before the shock are plotted as ordinal beats 6.5 and 7.5. Since these beats carry the largest weight in demonstrating the conditioned effect, it is necessary to explain the numbering system at this juncture. These beats are most easily understood as the last and next-to-last beat before the shock. They would be numbered 2 and 1 respectively if we counted in the direction of shock to tone. They have a different ordinal number if we start to count beats immediately after the tone, however. They have an average rank of 6.5 and 7.5 respectively when we use the tone as starting reference. This was the only unbiased way in which all subjects would be represented in each beat. All subjects had at least six beats following the tone, and of course all subjects had a last and next-to-last beat before the shock. The only error introduced by

Fig. 1   The forms of the unconditioned and conditioned responses of the heart.   The ordinate has the dimension of average heart-rate in beats per minute.   The abscissa represents the ordinal number of heartbeats, counting away from the tone and shock as reference points in the trial cycle.

On the top half of the figure the solid line shows the unconditioned response to the tone during the first 20 pre-conditioning trials of tone-alone.   The heart shows a wave-like disturbance with onset of tone.   For this function there is no shock during the 8-beat period labelled shock.

The dotted line on the top half of the figure shows the conditioned response to the tone during the 8-beat period marked post-tone, and the unconditioned response to shock during the periods labelled shock and post-shock.

Both of the above functions are averages of 17 subjects taken over 20 trials.

The dotted line on the bottom half of the figure is a plot of the differences between the two curves on the top half of the figure.   The solid line is a similar function using the last ten pre-conditioning trials as a correction instead of the entire 20 trials.

Figure 1
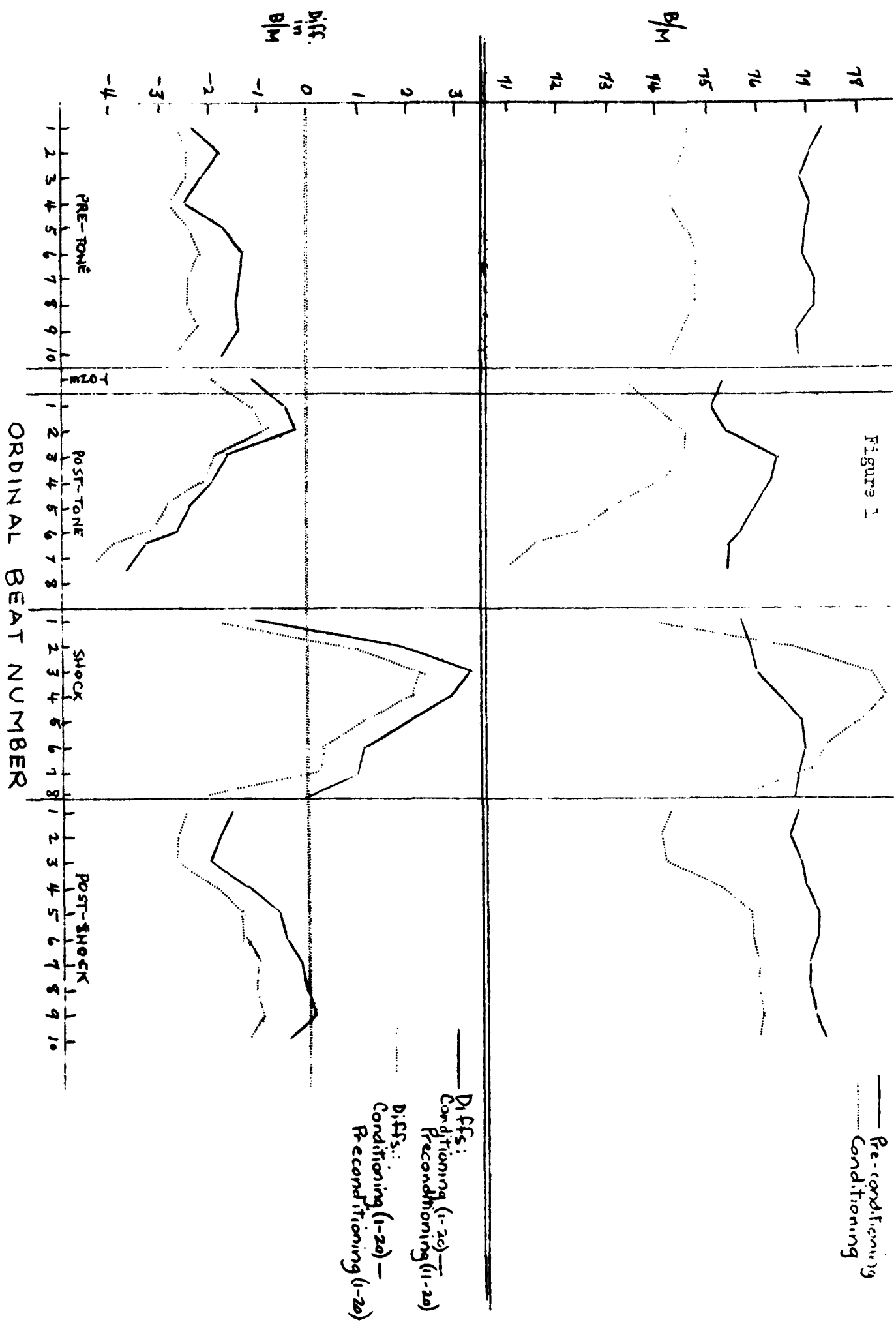
this counting system is that some subjects have one of their sixth beats averaged into not only the sixth beat but also the 6.5th beat.

Shock UR.-- The effect of the shock is to sharply elevate the heart-rate. From the trough brought about by conditioning the rate is brought up about 7½ b/m within the first 4 beats of the shock period. While the shock is still on, the heart-rate starts its return to the pre-tone level. A second rise is apparent in the post-shock period, and for those subjects whose records were analyzed for 20 post-shock beats a series of damped oscillations appeared. The shock UR is similar to the tone UR in being a wave-like disturbance in rate.

The CR corrected for tone UR.-- Since our CS was by no means a neutral stimulus, an attempt has been made to correct for this difficulty. If the form and magnitude of the tone UR have been accurately assessed during the pre-conditioning period, and this response tendency remains constant throughout conditioning, a straightforward correction would consist of a subtraction of the response during the first 20 trials from that measured during the second 20 (conditioning) trials. The bottom half of Fig. I shows the result of this correction. The dotted line shows the difference between the two functions plotted in the top half of Fig. I. Thus corrected the CR becomes first a rise in rate over the pre-tone level and then a drop before the shock. It is possible that this initial rise is an artifact. If the tone UR has adapted out by the time that conditioning begins, just such a rise would result from this correction procedure. As a check against this possibility, a correction has been made using only the last ten pre-conditioning trials. If tone UR adaptation were occurring, the initial rise effect would disappear. The solid line depicts the result of this correction. The parallelism of the two curves is evidence against the notion that the initial rise is an artifact due to adaptation.

The negative values of the corrected CR mean only that the overall level of heart-rate (the tidal level, so to speak) had fallen progressively throughout the course of the experiment.

Form of the pseudo-conditioned response.-- There are three functions instead of two to be presented for the 11 pseudo-conditioning subjects: one showing the form of the tone UR during the pre-conditioning phase, one showing the form of the tone response during the pseudo-conditioning phase, and another the UR to shock.

The solid line function in the top half of Fig. 2 shows the tone UR averaged over the first 20 pre-conditioning trials. It was computed in exactly the same way as the analogous function in Fig. 1, and the results differ very little. The first compensatory rise after the tone is slightly higher for the pseudo group than for the conditioning group, but that is all.

Fig. 2 The forms of unconditioned and pseudoconditioned responses of the heart. The abscissa and ordinate are the same as those of Fig. 1.

For the top half of the figure, the solid line shows the unconditioned response to the tone during the 20 pre-conditioning trials. There is no shock during these trials.

The dotted line shows the presumably pseudoconditioned response to the tone during ten trials of pseudoconditioning.

The dashed line shows the unconditioned response to shock during the five shock-alone trials of pseudoconditioning.

All the curves in the top half of the figure are based on averages of 11 subjects.

The bottom half of the figure shows the difference (dotted line) between the pre-conditioning (solid line) and tone alone (dotted line) curves of the top half of the figure. The solid line uses the last ten trials of pre-conditioning as correction factors.

Figure 2
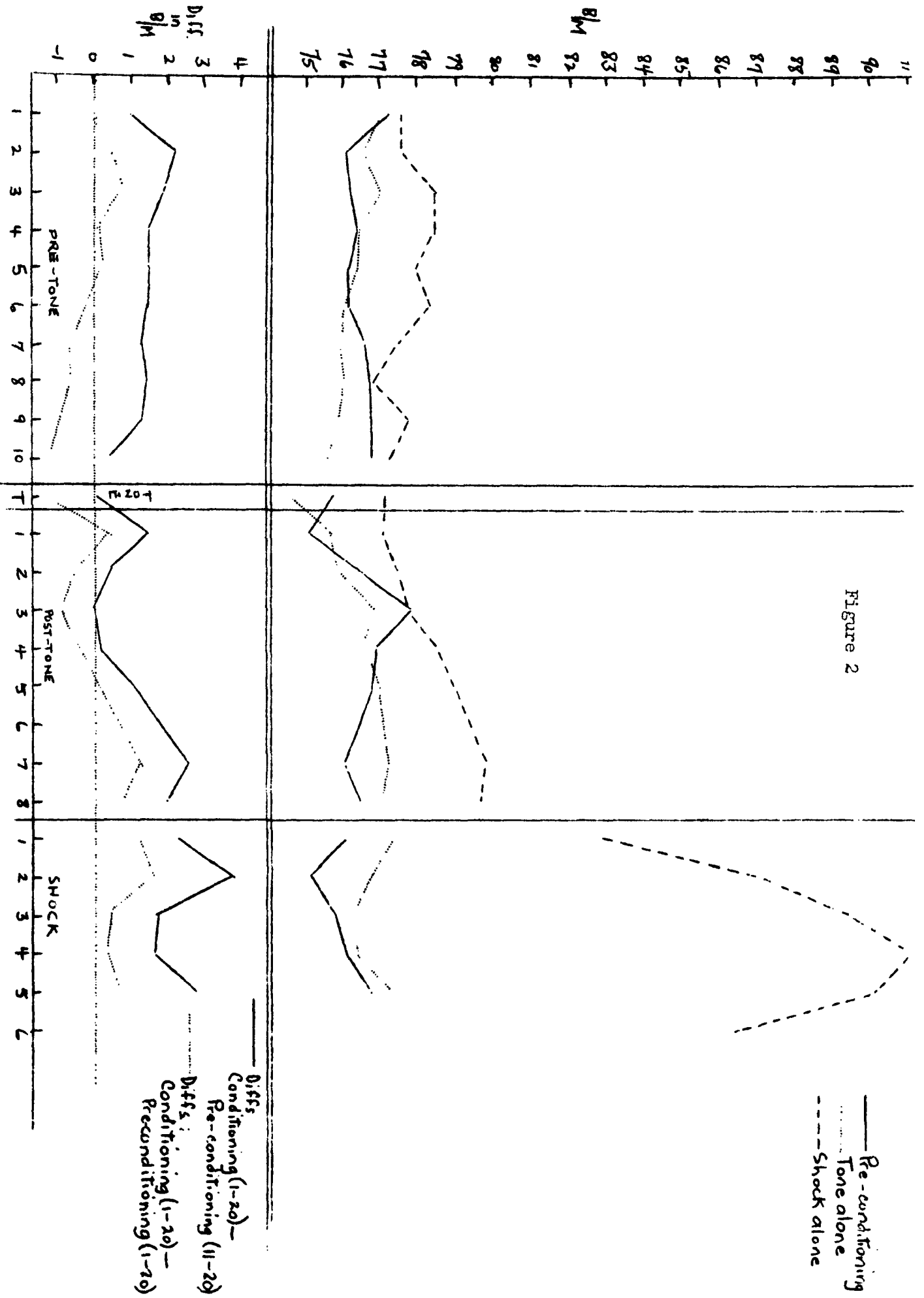
The shock UR (dashed line) also resembles closely that obtained from the conditioning subjects. The fact that the overall rate level is higher on the shock trials than on the others can be attributed to momentary fluctuation of general level during the pseudo-conditioning trials. The shock curve is made up of an average of only five shock trials in comparison to the other two more stable functions containing averages of 10 and 20 trials. One significant feature of the function representing these five shock-alone trials is the absence of any response during the period where the tone would normally be. This can be interpreted as proof of the absence of any extraneous cues from the apparatus or experimenters serving as a warning of approaching shock.

The dotted line is made up of the averages from the five pairs of tone-alone trials during the pseudo-conditioning trials. Each pair followed one of the five shock-alone trials. These ten trials were selected on the grounds that pseudo-conditioning would be expected to be greatest here, if anywhere. The unconditioned response to tone is still in evidence, and its form and magnitude are not changed greatly despite its being interspersed among a series of shocks. We consider our pseudo-conditioning procedure as more rigorous than that previously employed (2) as control because it more closely approximates the conditioning procedure (tone and shock) without including the CS-US pairing feature that defines conditioning.

The difference functions on the lower half of Fig. 2 are analogous to those of Fig. 1. The dotted line expresses the difference between the response to tone during the first 20 trials and the response to tone during the second 20. This function fluctuates about the zero difference level for most of the response. If we compute a mean and standard deviation from the ten pre-tone values, only one of the points after the tone lies more than two S.D. units away from the pre-tone mean. A significant pseudo-conditioned response is clearly absent. What little tendency there is for a sensitization or pseudo-conditioning effect is in a direction opposite to that of the conditioned effect. The tail-end of the response seems to be slightly elevated rather than depressed.

Using the average of the last ten pre-conditioning trials as a correction factor does not alter this conclusion (solid line).

The course of conditioning--the initial rise effect.-- It is necessary, next, to trace the course of development of the conditioned heart-rate response in a trial-by-trial fashion. We shall first fractionate the CR into nine parts consisting of the nine beat components during the tone and post-tone periods. Each of these will be treated as a separate response to see which ones yield characteristic learning curves. Since the corrected CR (lower half of Fig. 1) showed that the early portion of the conditioned response was an elevation in rate, while the later portion was a depression, the two portions have been plotted separately. Consider first the

beat during the tone (T-1), and the three beats following it during
the post-tone period (beats C-1, C-2, and C-3). It is convenient
to express these beat values as differences from pre-tone level since
the latter vary considerably, and the response we are interested in
is a deviation from overall level (the ripples on the tide, not the
tide itself). The right hand side of Fig. 3 shows the course of
change during the first 8 conditioning trials. Included on the left
side of the figure are the changes during the last 9 trials of pre-
conditioning. The left side gives us a basis for estimating changes
in response due to adaptation and to momentary fluctuation in rate.

As a detailed example we can read the C-1 function as follows.
The first beat after the tone has a value of about 2.4 b/m on the
trial numbered 13. This means that at this stage of pre-conditioning
(trials 12, 13 and 14 averaged) the first post-tone beat was 2.4 b/m
slower than the mean of the ten pre-tone beats. By trial 19 its value
has followed an irregular course downward (adaptation) until con-
ditioning begins. Conditioning produces a fall in the curve beyond
that which would be expected by adaptation. This sudden fall (the
loss of a slow-down) is responsible for the initial rise effect in
the form of the corrected CR shown in Fig. 1. The change brought
about by the conditioning procedure is not permanent,however.
There is a recovery to the pre-conditioning level by trial 7,
demonstrating that the effect is a temporary one and thus not inter-
pretable as due to conditioning.

A similar interpretation can be made of the other functions.
Beat C-2 in particular follows a course similar to that of C-1.
Whatever effect is present is not stable enought to be termed
conditioning.

The course of conditioning--the depression effect.-- Fig. 4 is
to be read like the previous figure. Here are plotted the values
for the remainder of the post-tone beats, C-4, C-5, C-6, C-6.5 and
C-7.5 representing the depressed portion of the CR. The values for
these beats are in general less variable during the last part of pre-
conditioning and quite regular during the conditioning trials. The
functions are readily interpretable as learning curves. The learning
reaches a plateau at about the 7th trial following which there is a
gradual decline in the magnitude of the CR out to trial twenty. The
response does not disappear, however, as is shown by the mean values
for the last five trials. This decline in strength of the CR may
be related to the adaptation of the shock UR.

Derivation of latency functions.-- In order to derive latency
functions from the conditioning curves presented in Fig. 4 we must
find out how early in the post-tone period the first significant
depression occurs. If we know on what beat the first significant
fall from pre-tone level occurs, the ordinal beat number can be
converted to a latency measure by adding up the amount of time
consumed by the earlier beats. A specific example will help ex-
position.

Fig. 3   The course of change over trials of the first
part of the conditioned response to tone. The ordinate ex-
presses the difference between the value of each beat in
beats per minute and the average of the last ten beats before
tone onset also in beats per minute. The abscissa is a moving
average of three trial blocks. Each block is numbered for
the middlemost trial in the block. The left hand side of the
graph indicates the changes in rate for the last nine trials
before conditioning trials start, while the right side shows
the progressive changes brought about by the first 8 trials
of conditioning.

The beat during tone (T-1) and the first three beats
immediately after the tone (C-1, C-2, C-3) are each plotted
separately. These beats control the initial elevated portion
of the CR to tone.

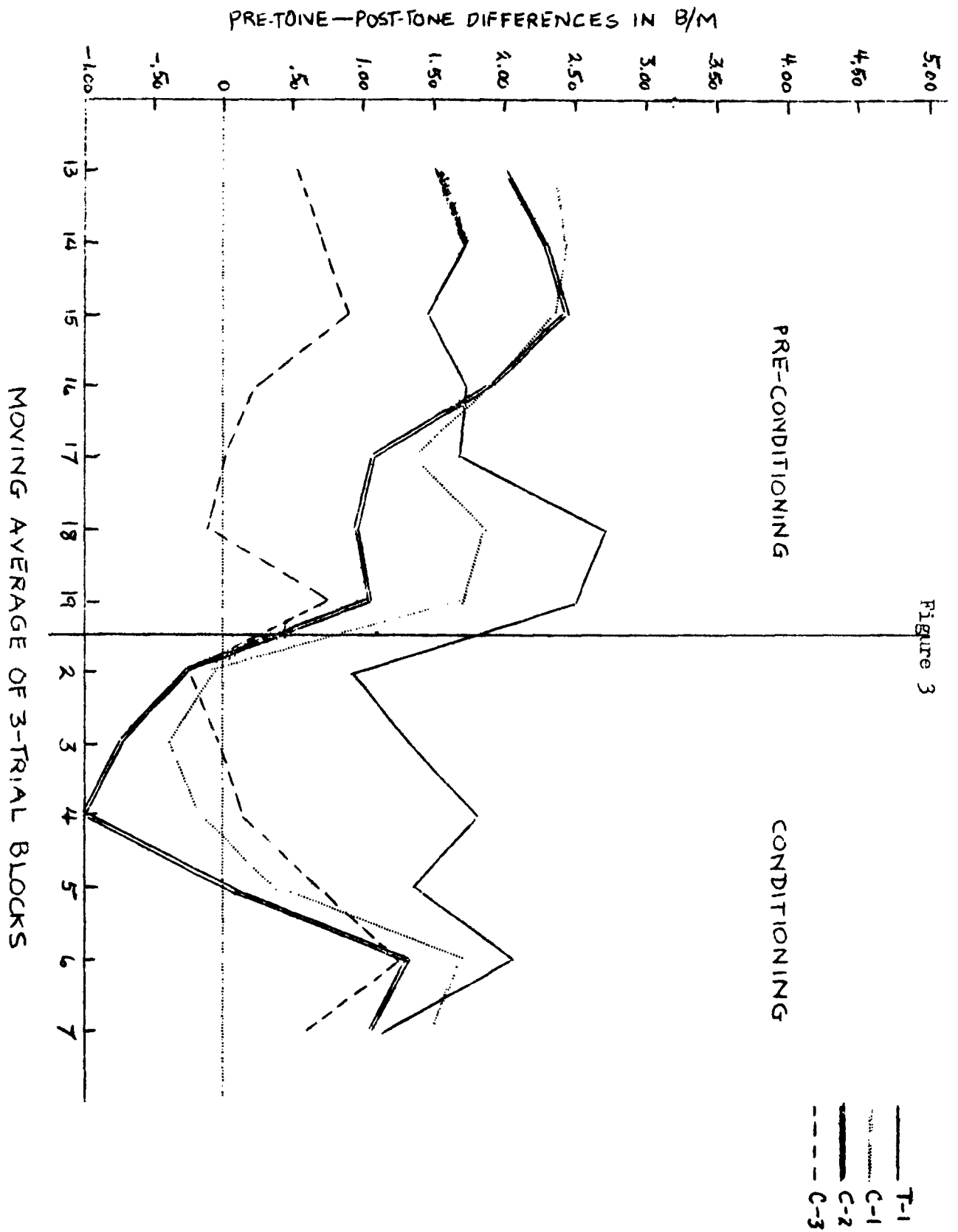The points represent the average of all 17 subjects.

Figure 3

Fig. 4   The course of change over trials of the last part (last five beats) of the CR to tone. The graph is to be read like Fig. 3. The last point on the abscissa numbered 18 represents the average of trials 16-20.

These five beats control the depressed portion of the CR to tone.

The points are the average of all 17 subjects.

Figure 4
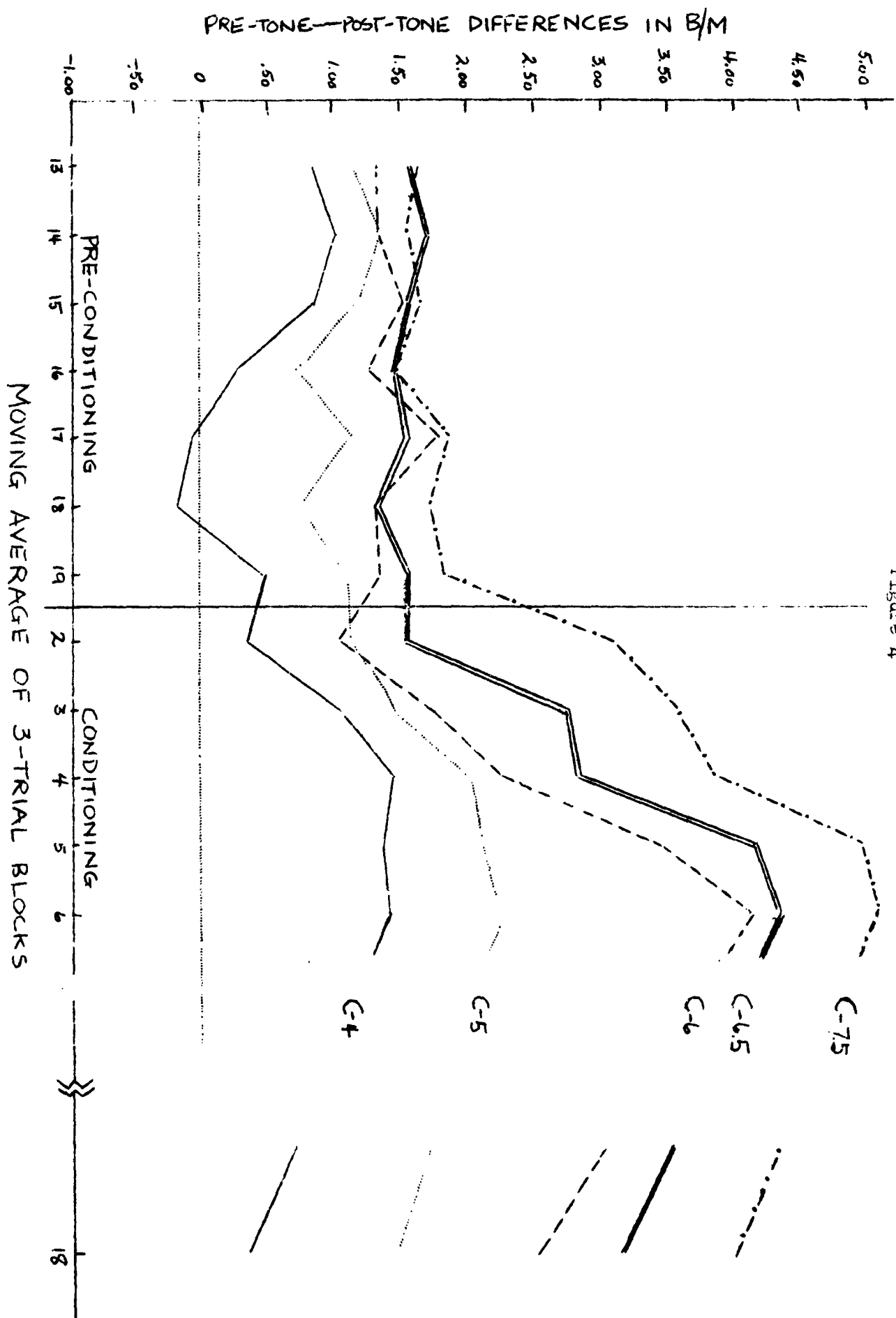
Consider the second block of conditioning trials in Fig. 4. Which
beat represents a conditioned response? The answer is that beat
which is significantly different from the pre-conditioning level.
The only beat which fits that description is C-7.5. If we find a
mean and S.D. for the last nine pre-conditioning trials of C-7.5, we
find that on trial 2 of conditioning, beat C-7.5 is more than 2.5 S.D.
units from the pre-conditioning mean. Hence beat C-7.5 indicates the
presence of a CR. Since no other beat is even one S.D. higher than
its own pre-conditioning mean, the CR latency is the latency of this
beat. Adding up the mean time per beat of each of the beats pre-
ceding C-7.5 we arrive at the value of 6.13 seconds. Adding to this
the one second of tone duration, the elapsed time between onset of
tone and the end of the first significant beat becomes 7.13 sec.
This is the CR latency at trial 2. The true value of this latency
must of course lie closer to 7.0 sec. since there are only seven
seconds between tone onset and shock onset. The computed value of
7.13 is plotted in Fig. 5 against trial 2.

On trial 3, the first beat showing a 2.5 S.D. deviation is
C-6.5 which occurs on the average 6.29 sec. after tone onset. This
value is plotted in Fig. 5 against trial 3. If one adopts a lower
level of significance, say that represented by 1.5 S.D. unit devia-
tions, then C-5 achieves significance on the trial. Beat C-5 is
completed on the average in 5.04 sec. after tone onset. This value
is plotted against trial 3. Two functions are thereby generated, one
for each of the two confidence levels employed. More curves could be
computed in this general fashion but none of them would have a
latency asymptote lower than that already plotted.

The overall shape of the latency curves is one of negative
acceleration with minimum points at 5 sec. (beat C-5) and 4.2 sec.
(beat C-4) for the high and low significance levels respectively.
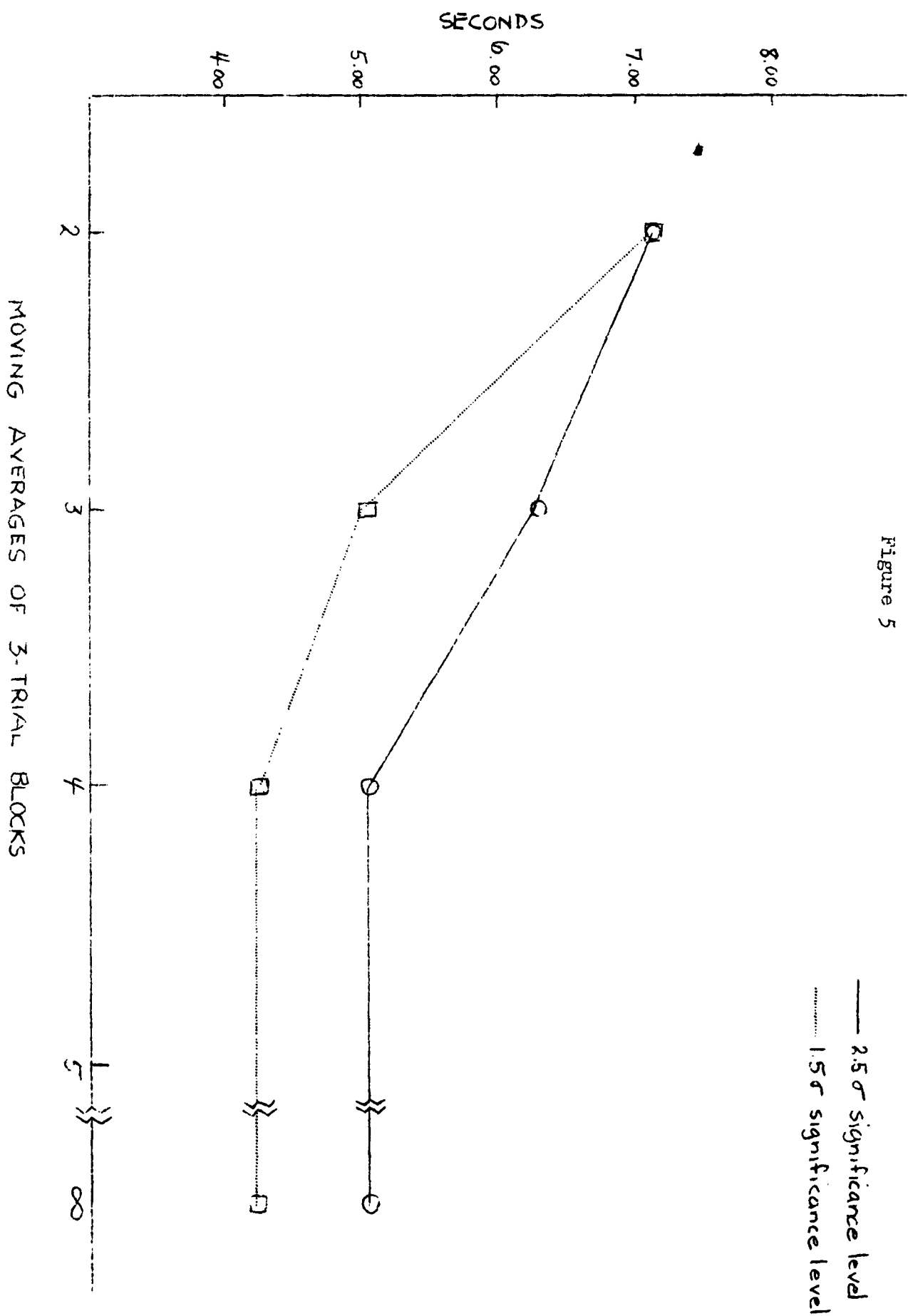

SUMMARY AND CONCLUSIONS

Latency and amplitude characteristics of a conditioned, human
heart-rate response have been described. Using a technique recently
developed by Notterman, Schoenfeld, and Bersh, 17 subjects were
conditioned and their records analyzed in beat-by-beat detail. A
rigorous pseudo-conditioning control procedure was devised and 11
subjects were run under this condition. The following conclusions
are supported by the data:

1. An unconditioned response of the heart to tone consists of
an initial drop in rate followed by a series of damped oscillations
in rate.

2. An unconditioned response of the heart to shock is an
elevation in rate also followed by damped oscillations.

Fig. 5   The latency of the conditioned depression in
heart-rate for the first six trials of conditioning. The
latency is measured by the time required for the first beat
following the tone to achieve a rate level significantly
different from the pre-tone level. The two curves are
derived from using two different levels of significance of
deviation from pre-tone level.

The points are averages of 17 subjects.

Figure 5

SECONDS

8.00
7.00
6.00
5.00
4.00

MOVING AVERAGES OF 3-TRIAL BLOCKS

2   3   4   5   8

——— 2.5 σ significance level
·········· 1.5 σ significance level

3. A conditioned response of the heart to a tone paired with shock consists of an exaggeration of the rate depression caused by tone.

4. No significant evidence of pseudo-conditioning was found.

5. Amplitude learning curves for the heart-rate CR were found to be negatively accelerated in shape with asymptotes at about the seventh trial.

6. A method was devised for measuring latencies of heart-rate CR's. Latency learning curves were found to be negatively accelerated with asymptotes at about the fourth trial.

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